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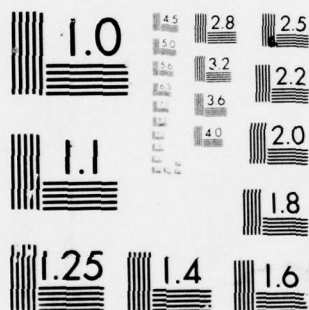
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Apparent Geographical Variations
Resulting from Rise and Fall of Sea Level,

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May 1976

(12) 19p.

EXEMPTED FROM GDS
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The Rand Corporation
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Apparent Geographical Variations
Resulting from Rise and Fall of Sea Level

A. B. Nelson

INTRODUCTION AND BACKGROUND

For the thousandth time, Jean Pierre stood on Montmartre and cursed the new, tall buildings blocking his view of the beautiful salt water Gulf of Paris joining Paris-sur-Mer with the English Channel. Fantasy? Perhaps, but certainly possible if all of the world's land-locked ice were to melt. The rise of sea level that would result from melting most of the present ice, as well as the previous (more extreme) ice-age lowering of the oceans, are illustrated in this paper.

In common usage, land elevations and ocean depths are given in terms of distance above or below mean sea level. While the "mean sea level" is not as ephemeral a reference point as "the old oak tree" or "farmer Brown's cow", it is not truly permanent. The level of the oceans (i.e., the "mean sea level") directly relates to the amount of water trapped as land-locked ice.

During the ice-ages of the Quaternary period, a succession of glaciations occurred that caused dramatic changes in sea level (eustasy). The glaciations may have been caused by some combination of events such as variations in the radiant energy emitted by the sun, the presence of interstellar dust clouds blocking the solar radiation, periodic changes affecting the earth's motion, or other phenomena, such as internal processes in the atmosphere and oceans. It is tempting (and fascinating) to speculate on the possible effects of massive engineering projects, poor land management, and man-made pollution on future local and global climate variations; however, such speculation is not within the scope of this paper.

The accumulation of enormous amounts of ice causes a warping of the underlying land (isostasy) and, conversely, the removal of an equivalent amount of water from the ocean causes a slight uplifting of the ocean floor. The isostatic changes contribute to some local changes in the relative sea level. The geological recovery from the warping caused by past glaciers is still underway: the vicinities of the Gulf of Bothnia and Hudson Bay have the greatest potential for future uplift (King, 1965). The effects of isostatic variations, however, were not considered in preparing the illustrations for this paper.

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HISTORICAL REALITIES AND SOME UNLIKELY POSSIBILITIES

About 18,000 years ago, the sea stood below its present level by at least 85 meters. Some estimates show a lowering of as much as 110 to 125 meters (Curry, 1965). The conservative 85 meter estimate would have exposed almost 10 million square kilometers of land, about seven percent more land area than at present - an area larger than the United States. This would remove approximately 30 million cubic kilometers of water from the ocean (the Mediterranean Sea, with an average depth of 1.5 kilometers, contains about one eighth of the volume removed). Among the more significant effects of removing this quantity of water from the ocean are the emergence of a land "bridge" joining Siberia with Alaska, and the connection of several islands with the mainland of Asia. These "bridges" were very likely used by migrating humans and other animals, causing a dispersion of species on a scale that would have been otherwise impossible. The drying of the Baltic Sea probably had less impact on human and animal movement, since the area was under several thousand feet of ice.

It is also possible for the oceans to rise above their present level; however, it is probable that the mean sea level has been only slightly above its present level during geologically recent times. In order to raise the sea level significantly (more than a few meters), the land-locked ice in the Antarctic would have to melt. The South Polar ice-cap contains over 23 million cubic kilometers of land-locked ice. If it melted, it would raise the water level by about 65 meters, causing the flooding of almost 9 million square kilometers of presently dry land. Since a great proportion of the world's cities and economic centers are situated in coastal areas, the flooding would be far more disastrous than the percent of land lost indicates. Extensive flooding would also occur in the usually agriculturally rich and heavily populated inland river valleys; for example, the elevation of Paris, France, ranges from 26 to 128 meters (Encyclopaedia Britannica, 1976) so that a major portion of it would be next to (or under, by as much as about 40 meters) the inlet that would be formed from the English Channel through the present course of the Seine River.

Fortunately, deliberately melting the Antarctic ice would be extremely difficult, since huge amounts of energy would be required: almost 2×10^{24} calories. This amount of energy is more than one million times the electrical production of the United States during 1975. It is about equal to the total amount of solar energy reaching the surface of the earth in 2.6 years.

COMPUTER PRESENTATION OF THE POSSIBLE AND THE FANCIFUL

The illustrations in this paper show the geographical changes that would result from variations in sea level. The first five figures illustrate the extents of land and sea as they are at present, as they were during the ice-age, and as they would be if the South Polar ice melted. The next eight figures show fanciful extremes of flooding and drying. The dots on the maps are at intervals of one degree of latitude and longitude. Convergence of the meridians is not depicted on the maps.

Fig. 1 shows the present dry land area. The land area resulting from a lowering of the sea level by 85 meters appears in Fig. 2a, while Fig. 3a shows the possible effects of melting the Antarctic ice sheet (i.e., a 65 meter rise of sea level). Figs. 2b and 3b show only the areas that would flood or dry in the event of the given changes in water level.

Practical considerations govern the extremes of possible eustacy. In the event of very extreme glaciations, the level of the oceans could fall far below the estimated previous lows. However, if all the land ice were melted, the sea level could not rise more than about 65 meters. Even adding all probable subsurface water would only raise the level by about 15 meters more. Thus, the limits of sea level in the real world are constrained by available water and, to a less well defined extent, by a reasonable estimated maximum glaciation. The limits of sea level in the computer are not so limited; therefore, it is possible to show hypothetical examples of extreme flooding and drying. Figs. 4-7 show the effects of raising and lowering the water level by the artificial amounts of 200 and 500 meters. These examples are not intended to show any real situation, but are included only to emphasize the varying topography of the world.

COMPUTATIONAL PROCEDURE AND DATA APPLICATIONS

The data used in preparing the maps (Gates and Nelson, 1975) consist of ocean depths and elevations on a one degree grid. The process of exposure and flooding was done in increments of one degree areas. In order to flood an area, it had to be below the designated sea level and be adjacent to a flooded or ocean area (i.e., no area was flooded that did not have an inlet to a flooded area). It was assumed that drying would occur uniformly; for this reason, the water level in areas such as the Mediterranean Sea continued to lower even after the connection to the ocean had been blocked. No attempt was made to account for the isostatic changes in land elevations caused by the accumulation or melting of ice, and no distinction was made between elevations of land without ice and elevations that are presently the result of ice accumulation.

Among other possible uses of these data, or of other more detailed data, might be the study of various wind patterns resulting from changed land elevations relative to sea level. It might also be applied to the study of potential off-shore oil fields and could be used to indicate the areas that have flooded as the old glaciers melted; for example, the areas in which flooding could have covered prehistoric living sites and evidence of ancient migrations along the continental shelves might be of interest to archaeologists and anthropologists.

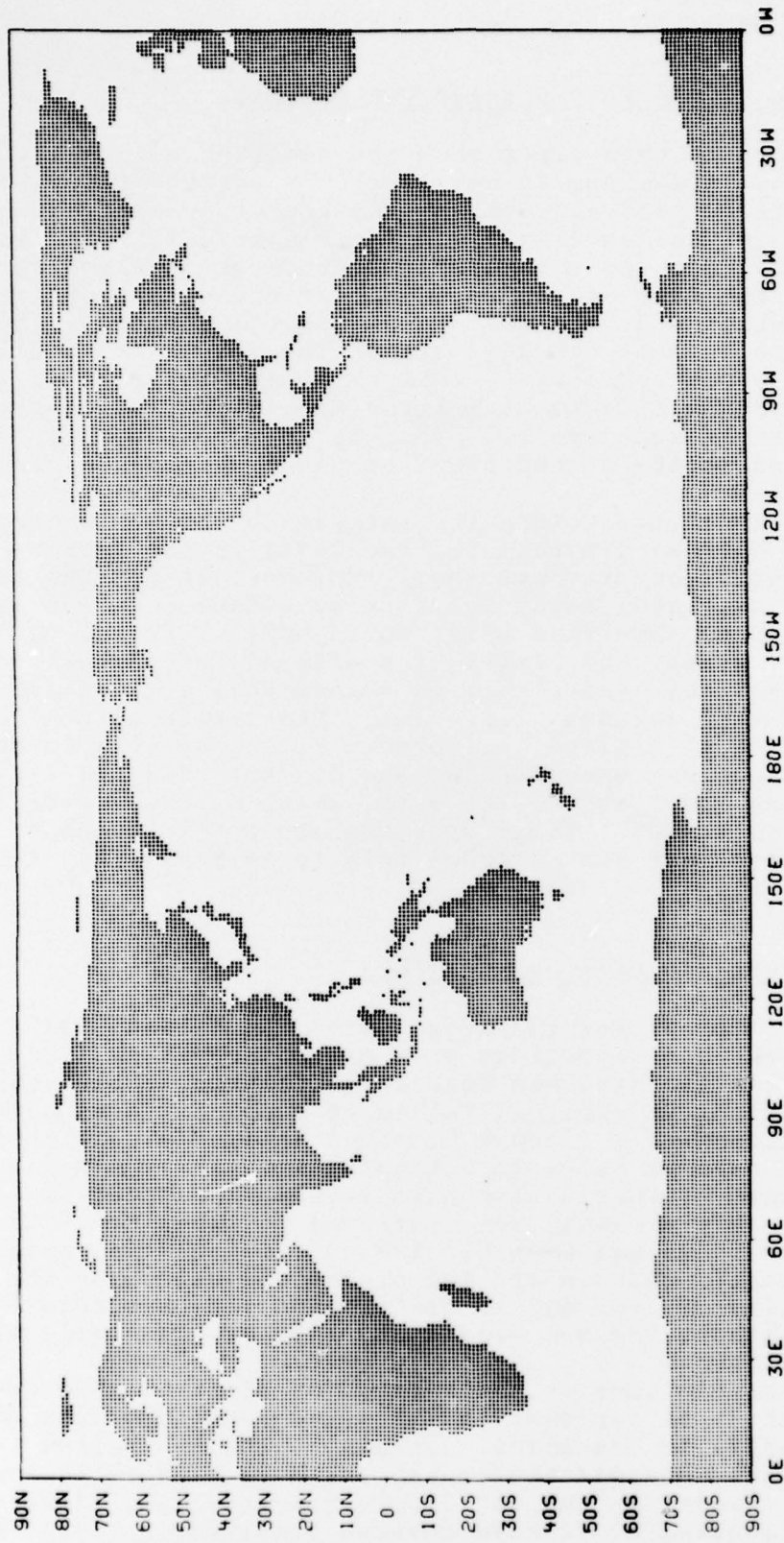


Fig. 1 EFFECTS OF EUSTATIC RISE AND FALL

WATER LEVEL CHANGE= 0M, CHANGE IN AREA OF OCEAN= 0.000 KM², CHANGE IN VOLUME OF OCEAN= 0.000 KM³

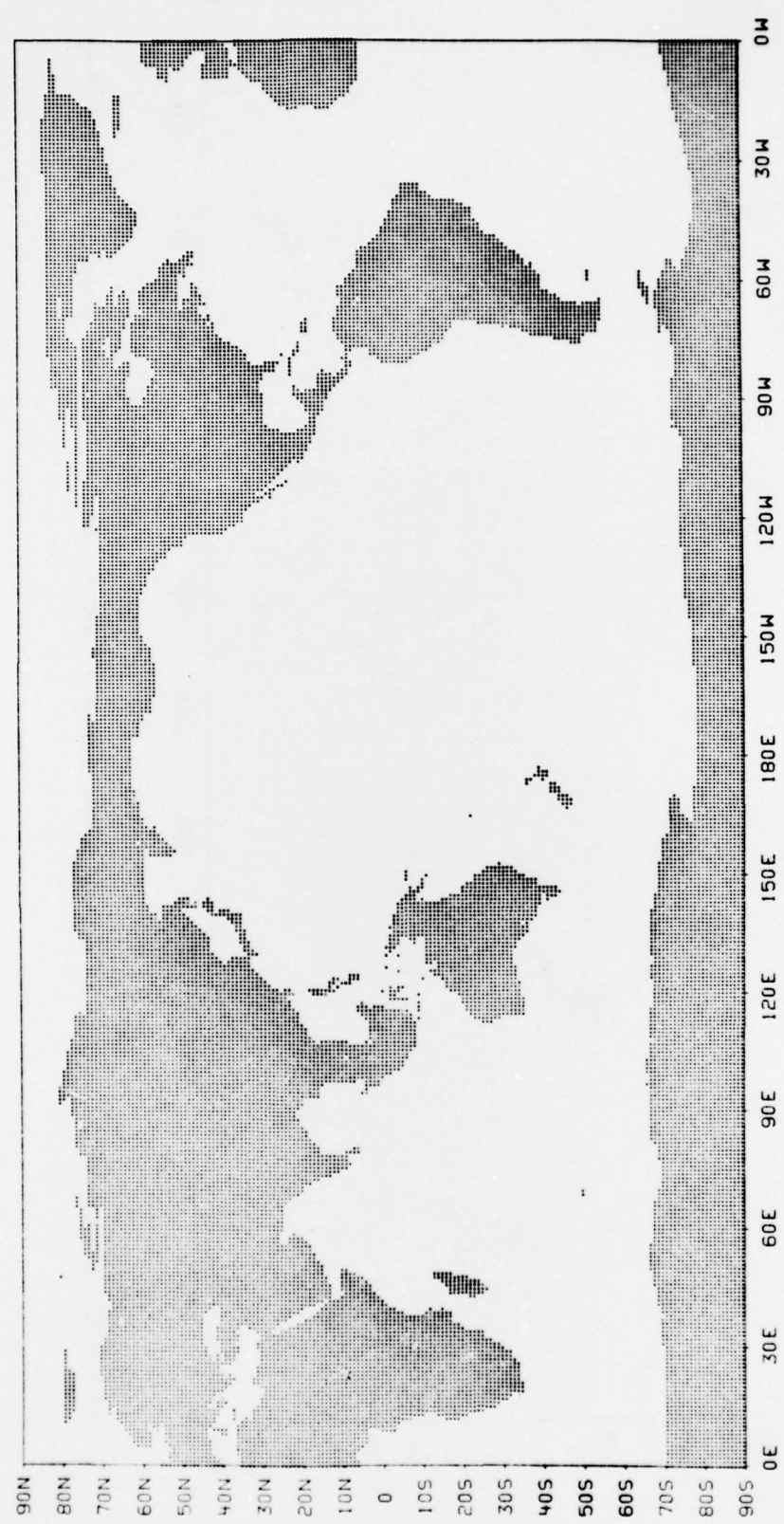


Fig. 2a

EFFECTS OF EUSTATIC RISE AND FALL

WATER LEVEL CHANGE = -85M, CHANGE IN AREA OF OCEAN = $-0.972 \times 10^{+07} \text{ KM}^2$, CHANGE IN VOLUME OF OCEAN = $-0.301 \times 10^{+08} \text{ KM}^3$

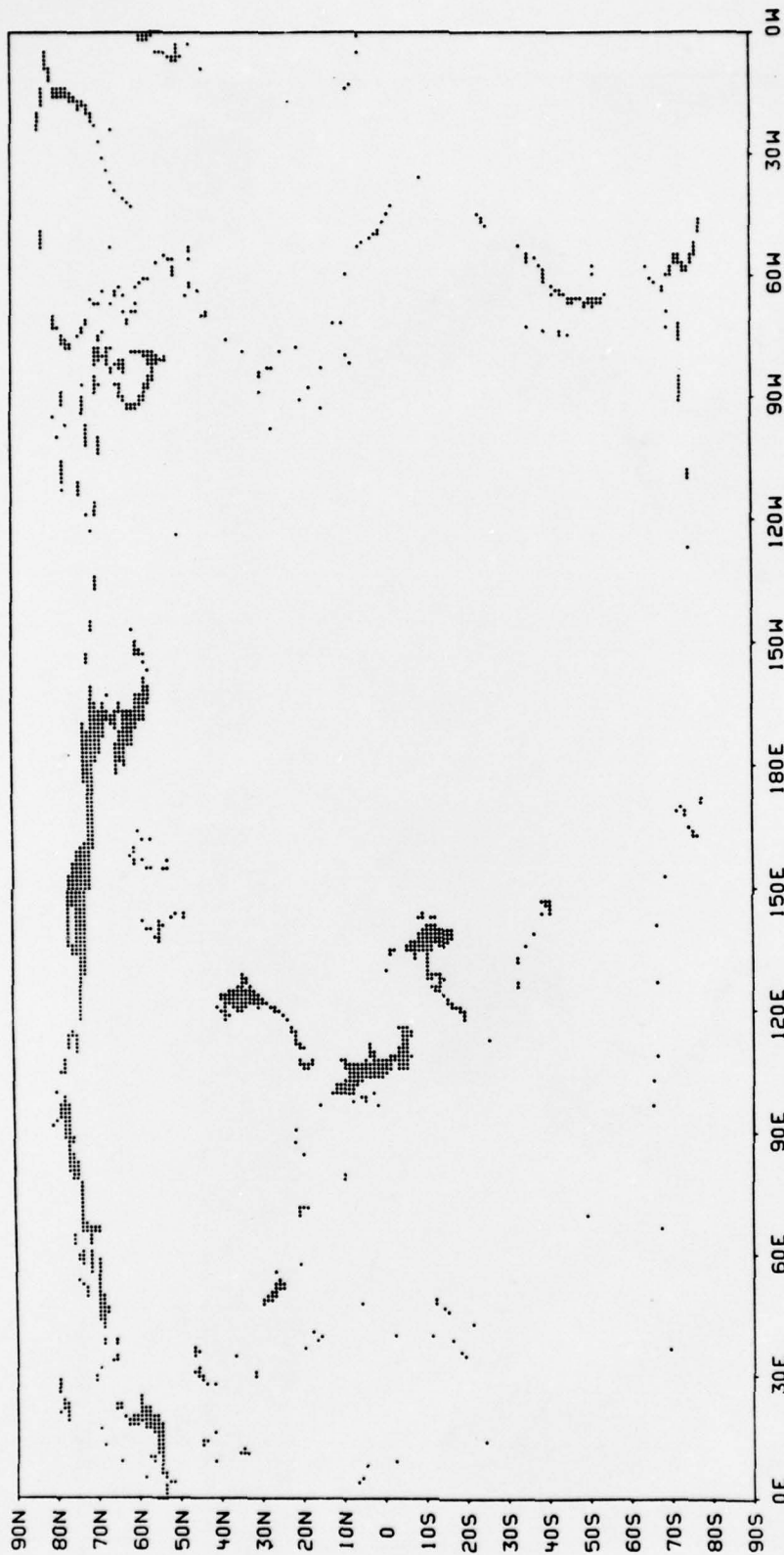


Fig. 2b

WATER LEVEL CHANGE = -85M, CHANGE IN AREA OF OCEAN = $-0.972 \times 10^{+07}$ KM², CHANGE IN VOLUME OF OCEAN = $-0.301 \times 10^{+08}$ KM³

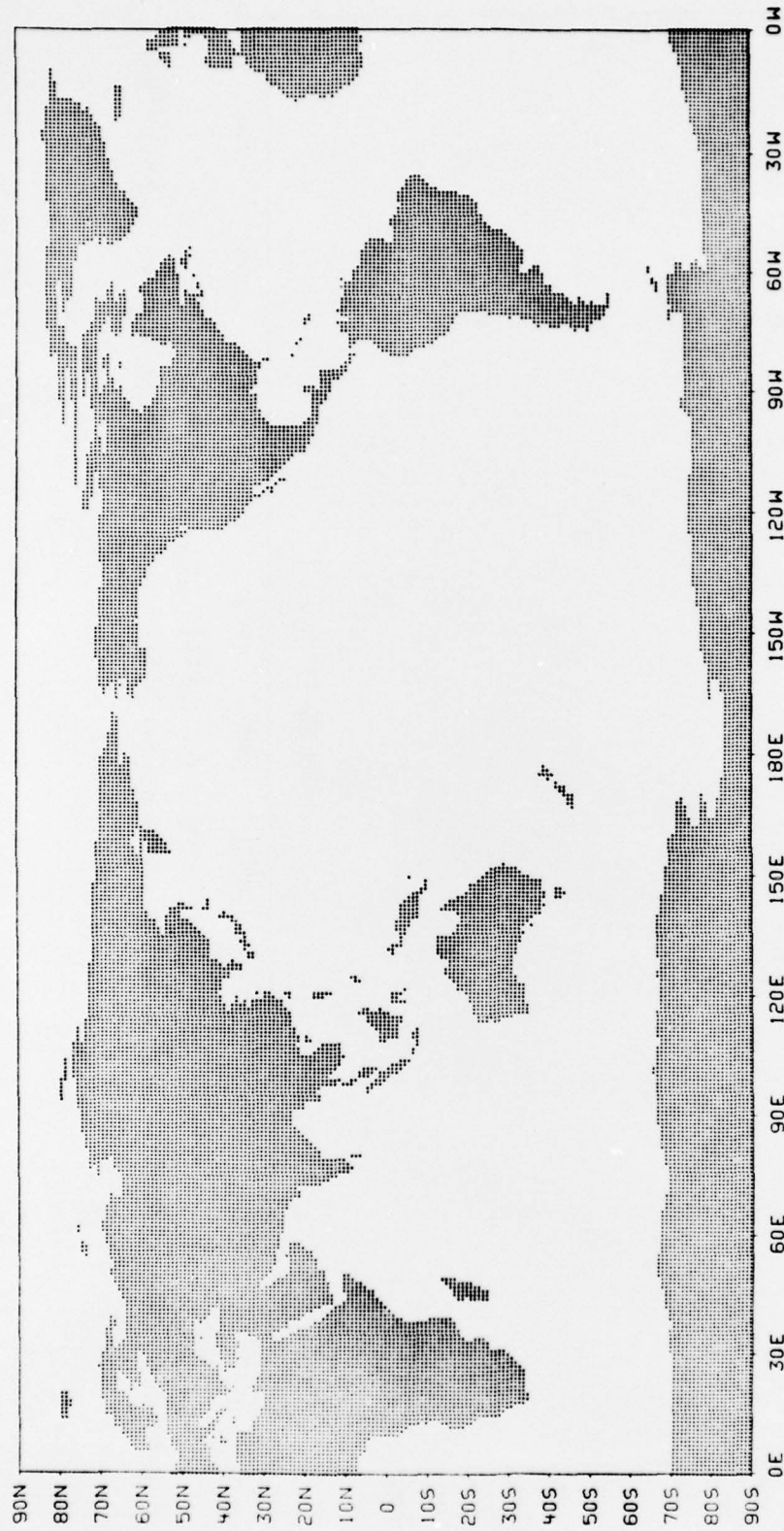


Fig. 3a EFFECTS OF EUSTATIC RISE AND FALL

WATER LEVEL CHANGE= 65M, CHANGE IN AREA OF OCEAN= $0.891 \times 10^{+07}$ KM², CHANGE IN VOLUME OF OCEAN= $0.237 \times 10^{+08}$ KM³

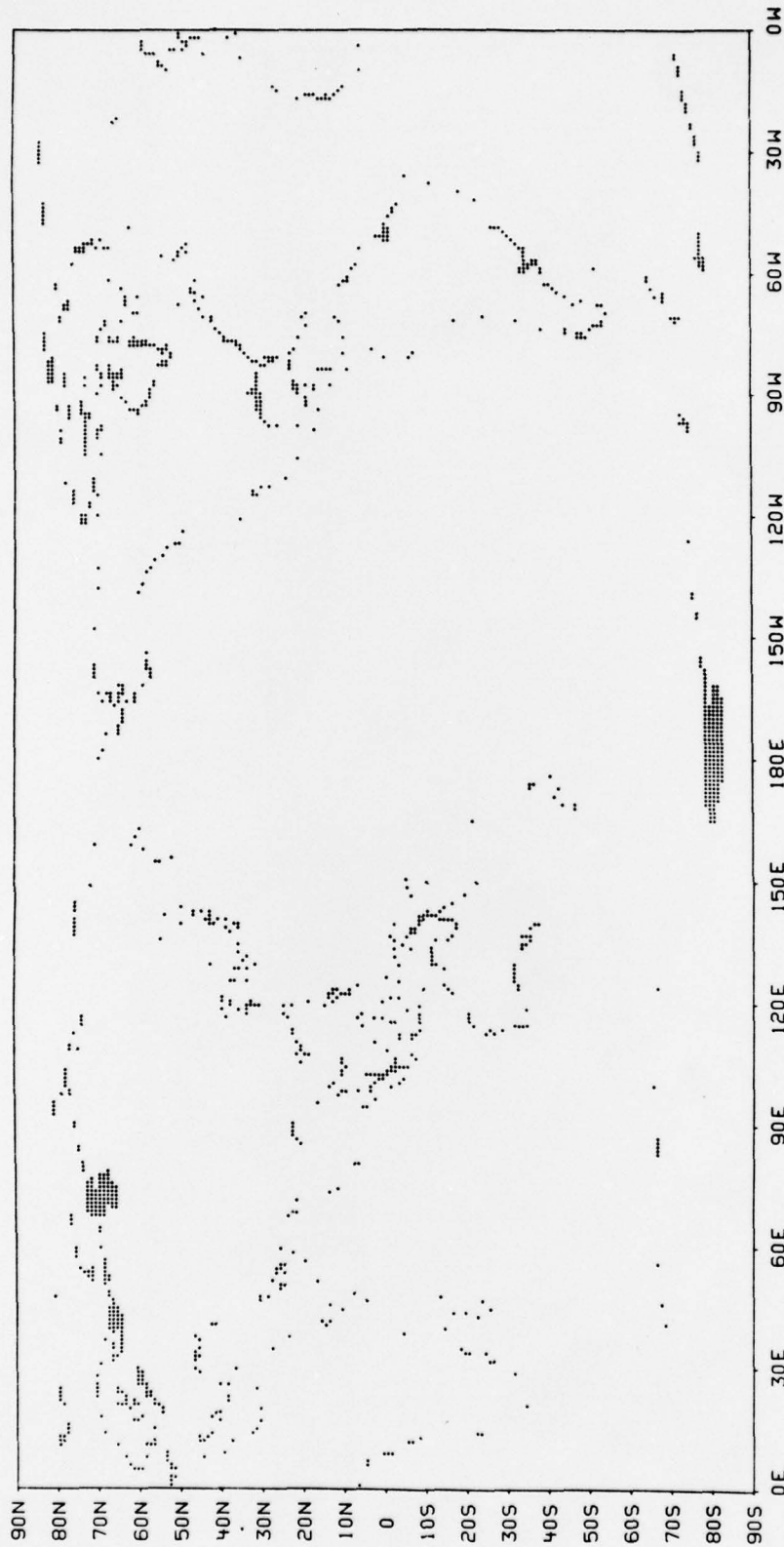


Fig. 3b LOCATIONS FLOODED BY WATER LEVEL CHANGE

WATER LEVEL CHANGE= 65M, CHANGE IN AREA OF OCEAN= $0.891 \times 10^{+07} \text{KM}^2$, CHANGE IN VOLUME OF OCEAN= $0.237 \times 10^{+08} \text{KM}^3$



Fig. 4a
EFFECTS OF EUSTATIC RISE AND FALL

WATER LEVEL CHANGE--200M, CHANGE IN AREA OF OCEAN-- $0.191 \times 10^{+08} \text{ km}^2$, CHANGE IN VOLUME OF OCEAN-- $0.696 \times 10^{+08} \text{ km}^3$

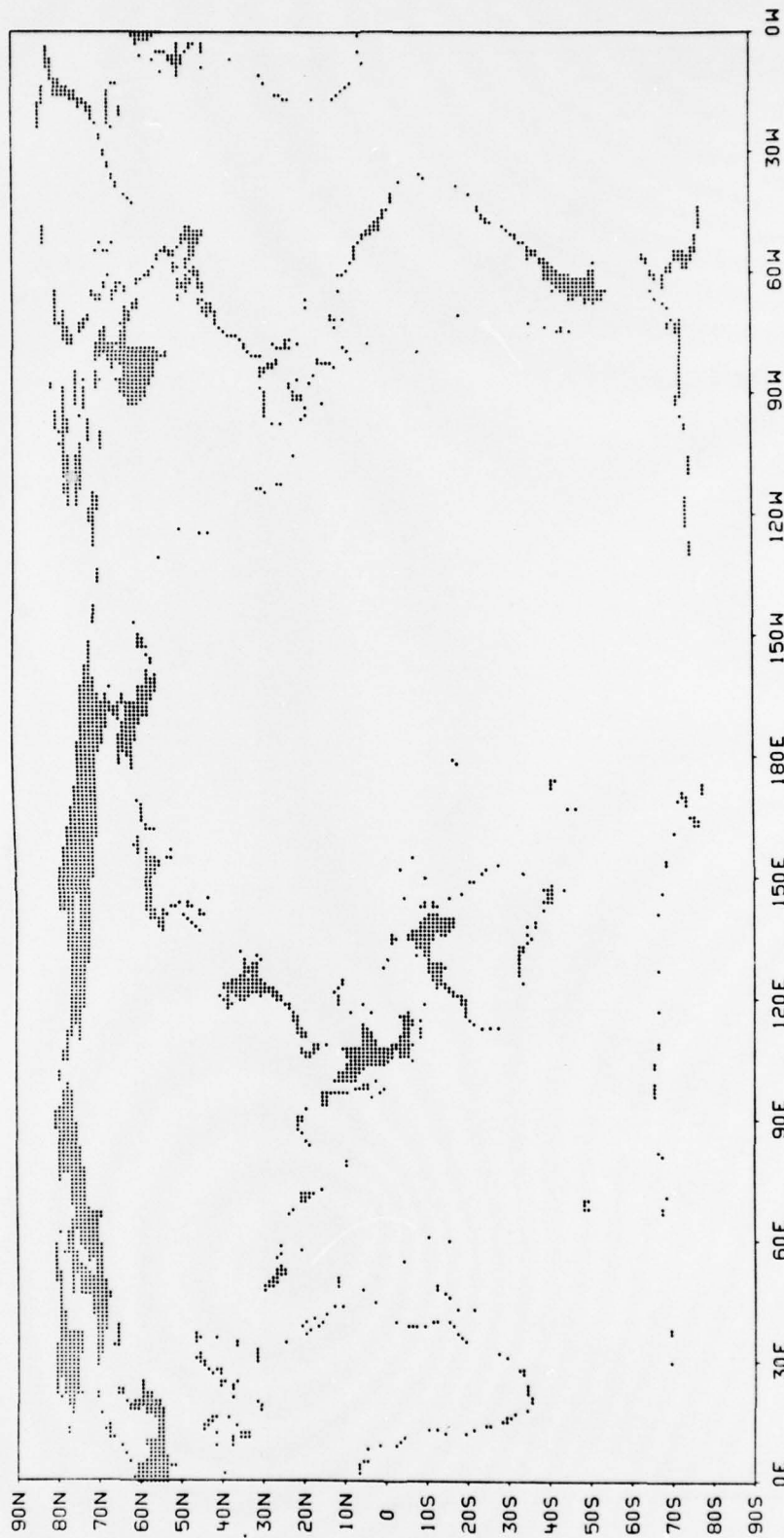


Fig. 4b

LOCATIONS EXPOSED BY WATER LEVEL CHANGE

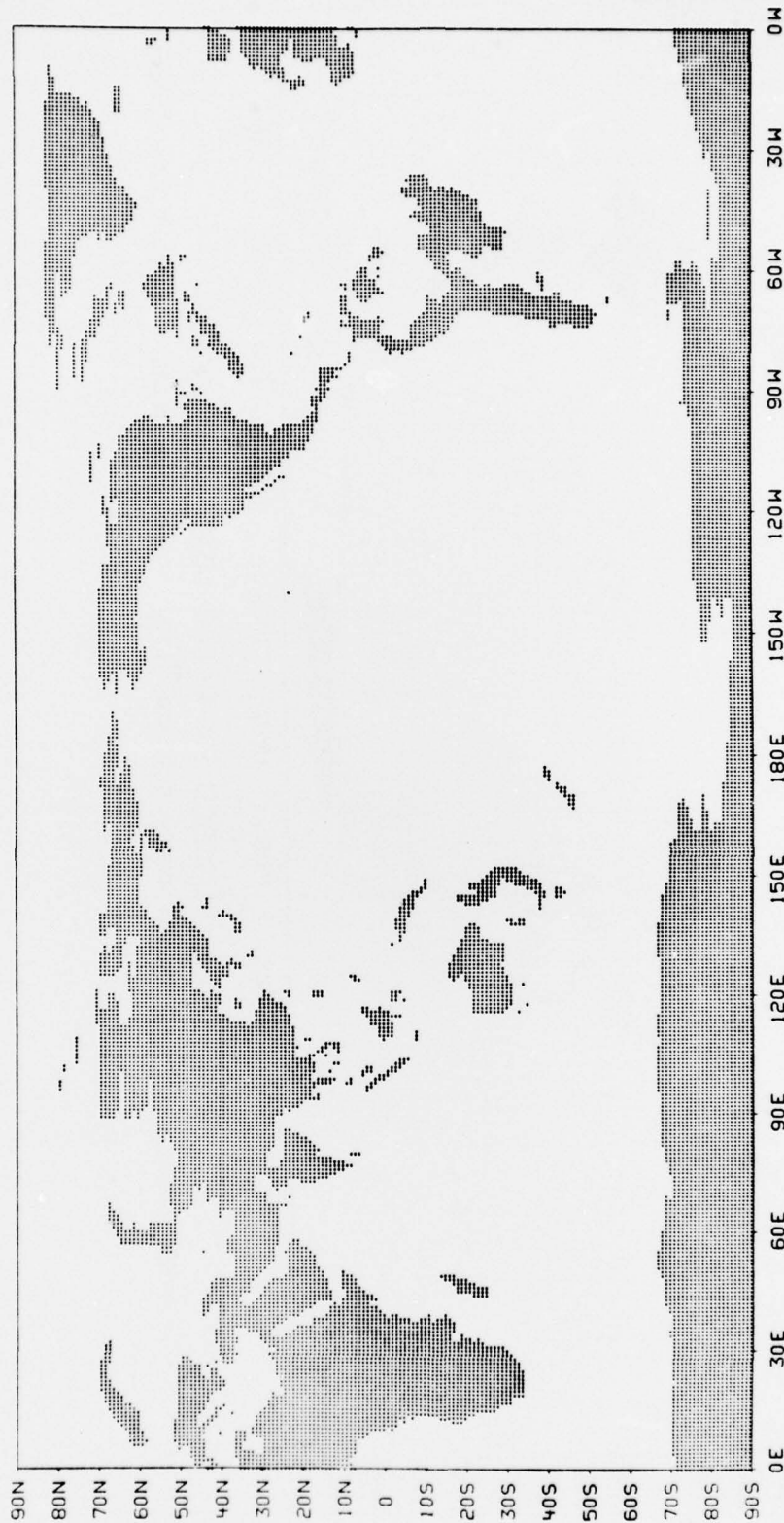


Fig. 5a

EFFECTS OF EUSTATIC RISE AND FALL

WATER LEVEL CHANGE= 200M, CHANGE IN AREA OF OCEAN= $0.480 \times 10^{+08}$ KM², CHANGE IN VOLUME OF OCEAN= $0.747 \times 10^{+08}$ KM³

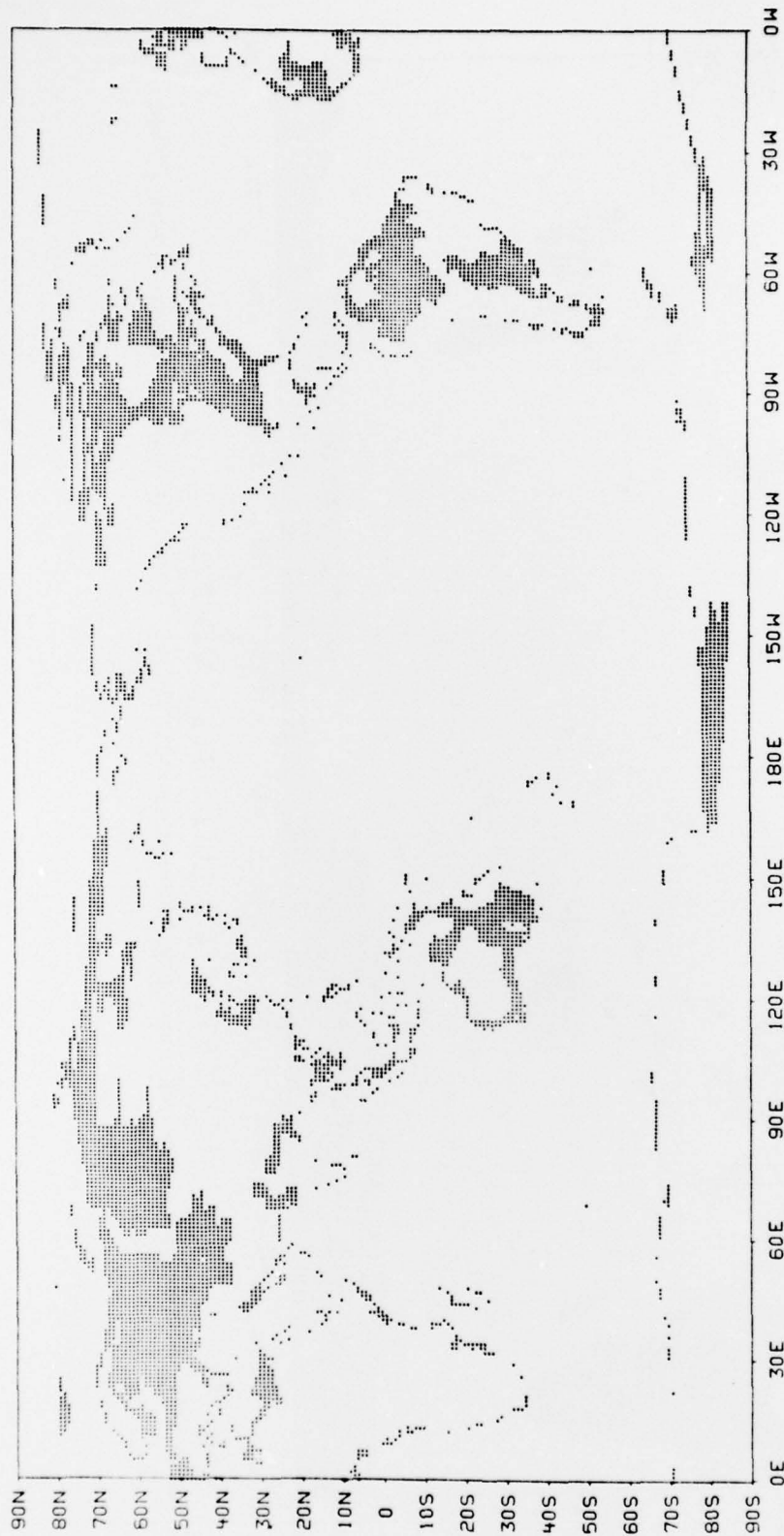


Fig. 5b LOCATIONS FLOODED BY WATER LEVEL CHANGE

WATER LEVEL CHANGE = 200M, CHANGE IN AREA OF OCEAN = $0.480 \times 10^{+08}$ KM², CHANGE IN VOLUME OF OCEAN = $0.747 \times 10^{+08}$ KM³

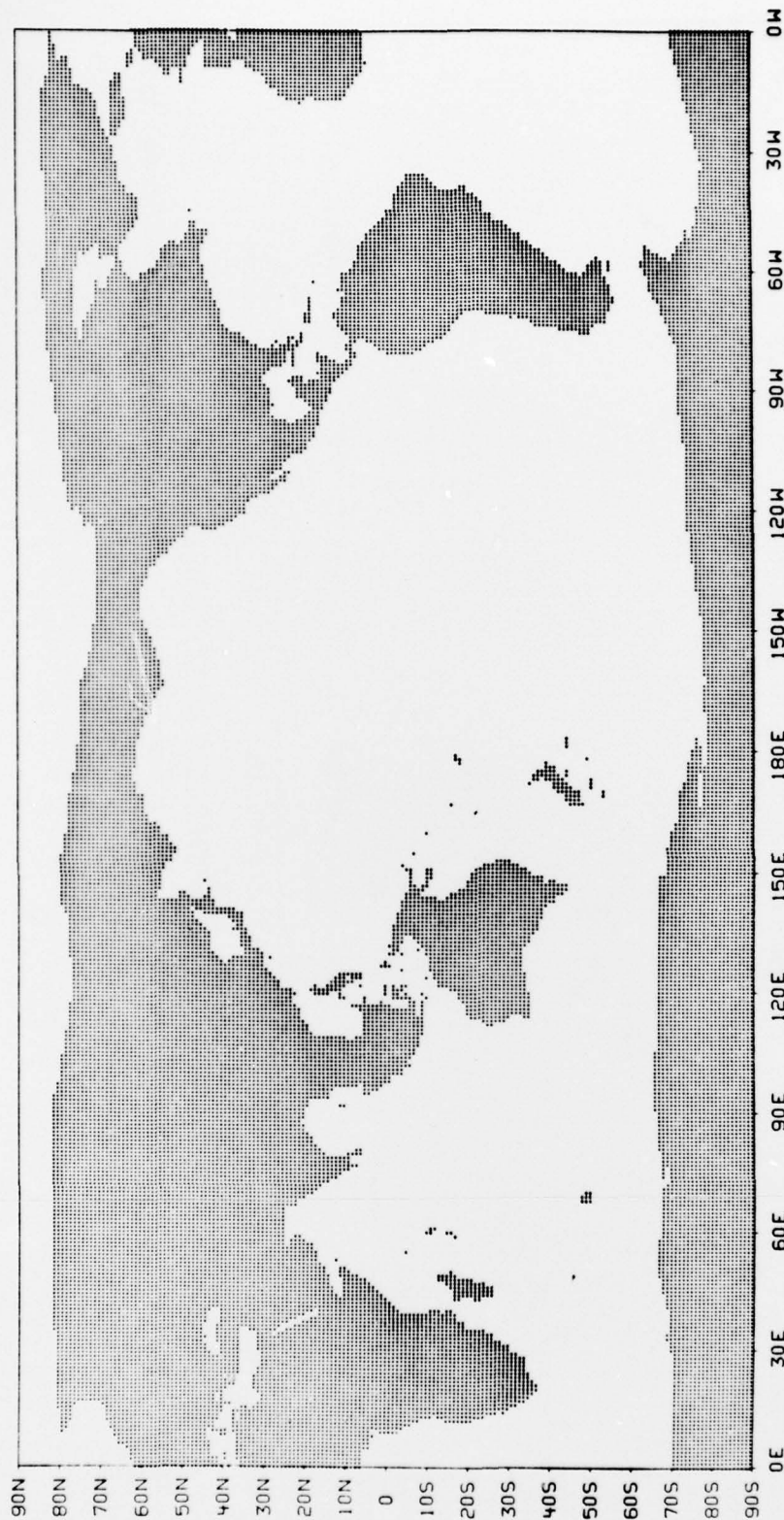


Fig. 6a

EFFECTS OF EUSTATIC RISE AND FALL

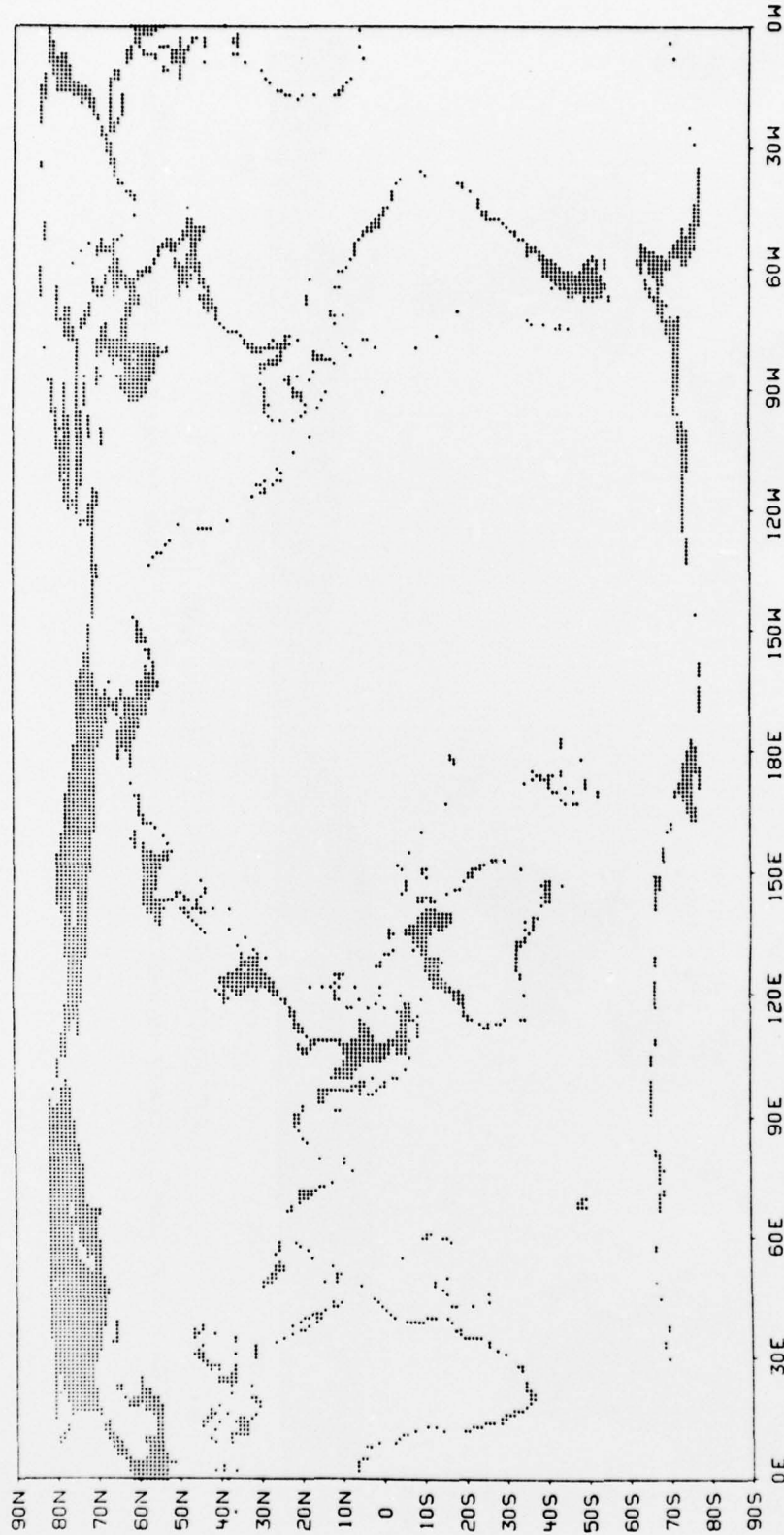


Fig. 6b

LOCATIONS EXPOSED BY WATER LEVEL CHANGE

WATER LEVEL CHANGE $\geq 500\text{M}$, CHANGE IN AREA OF OCEAN $= -0.268 \times 10^{+08} \text{KM}^2$, CHANGE IN VOLUME OF OCEAN $= -0.171 \times 10^{+09} \text{KM}^3$

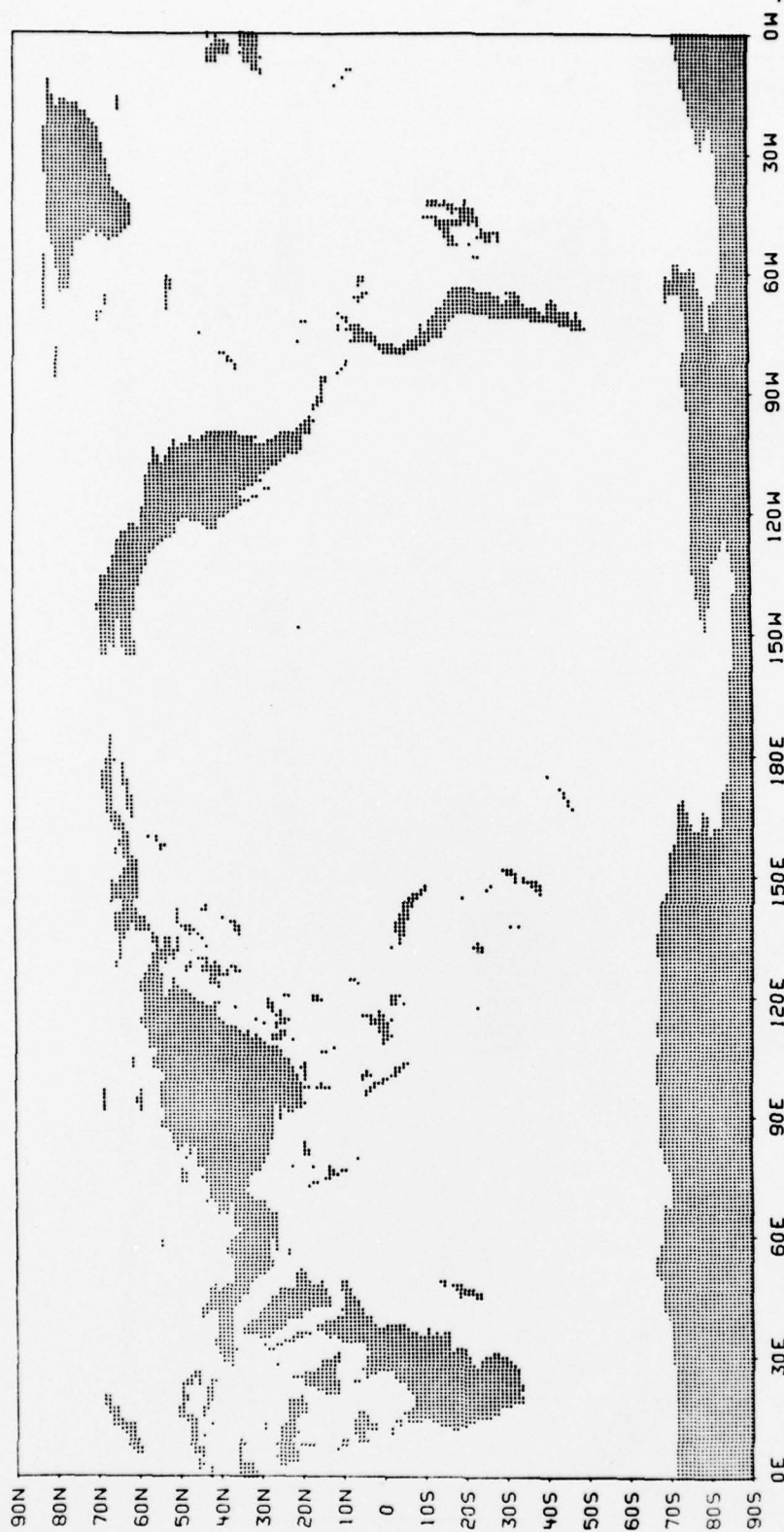


Fig. 7a

EFFECTS OF EUSTATIC RISE AND FALL

WATER LEVEL CHANGE = 500M, CHANGE IN AREA OF OCEAN = $0.908 \times 10^{+08} \text{ KM}^2$, CHANGE IN VOLUME OF OCEAN = $0.202 \times 10^{+09} \text{ KM}^3$

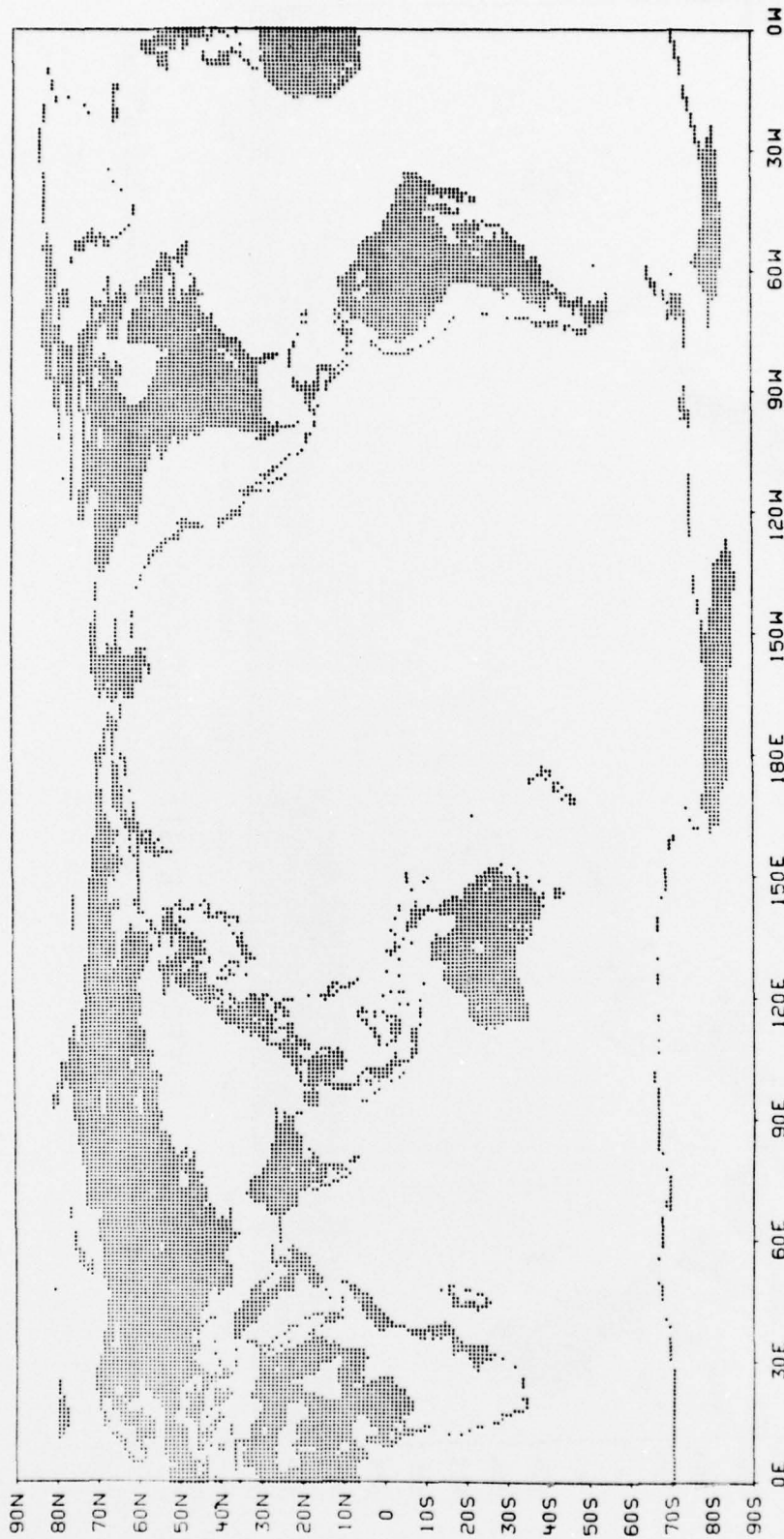


Fig. 7b

LOCATIONS FLOODED BY WATER LEVEL CHANGE

WATER LEVEL CHANGE = 500M,

CHANGE IN AREA OF OCEAN = $0.908 \times 10^{+08} \text{ KM}^2$,

CHANGE IN VOLUME OF OCEAN = $0.202 \times 10^{+09} \text{ KM}^3$

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